3. DATA CHARACTERISTICS

3.1. SATELLITE RADIOMETER DESCRIPTIONS

The primary ISCCP dataset is radiance data obtained from a global set of operational weather satellite imaging radiometers, which have in common a narrow-band spectral channel at about 0.6 μm wavelength, near the peak of the solar spectrum, and one in the atmosphere's thermal infrared opacity "window" near 11 μm wavelength. Some of these radiometers have additional spectral channels. The spatial resolution of the raw images ranges between 1 - 4 km (visible channel) and between 5 - 11 km (infrared channel). Imaging frequency (for a specific low latitude location) varies from 14 to 48 times per day for geostationary satellites to twice daily for each polar orbiting satellite. Currently operating satellite systems are METEOSAT, GOES, GMS and INSAT (geostationary) and the NOAA polar orbiters. Details of the satellites and imaging radiometers are provided in Tables 3.2 and 3.3.

3.1.1. NOAA

This satellite program (Kidwell 1995) is a cooperative effort of the USA, the United Kingdom and France for providing global environmental observations. The National Oceanic and Atmospheric Administration (NOAA) is the operating agency. Tiros-N was the NASA prototype R-and-D spacecraft launched in late 1978; the operational system usually consists of two polar orbiting, sun-synchronous satellites crossing the equator during local morning and afternoon (and corresponding nighttimes). At the start of ISCCP data collection in July 1983, NOAA-7 was the afternoon satellite supplying imaging data. NOAA-8 data were collected starting in October 1983 to augment observation of the Indian Ocean sector. The subsequent operations history is given in Table 3.1.

The spacecraft in this series are three-axis stabilized in 850 km (nominal) circular, near-polar, sun-synchronous orbits with an inclination angle of ~ 99° (retrograde) to the equator. Orbital period is about 102 minutes. Sequential orbits observe adjacent longitudes near the equator and provide overlapping coverage in both polar regions. The imaging instrument is the Advanced Very High Resolution Radiometer (AVHRR) which has up to five spectral channels (wavelengths ≈ 0.65, 0.85, 3.7, 10.7 and 11.7 μm) with a nadir resolution of 1.1 km. Global data are only available with (nominal) 4 km resolution. Tables 3.2. and 3.3 show more detail.

Also on the polar orbiting satellites is a suite of instruments which provide routine temperature sounding and ozone observations. Products obtained from these data are utilized in the ISCCP analysis of B3 data. These instruments, the Microwave Sounding Unit (MSU), the Stratospheric Sounding Unit (SSU) and the High Resolution Infrared Sounder 2 (HIRS/2), comprise the TIROS Operational Vertical Sounder (TOVS).

3.1.2. METEOSAT

This system, previously operated by the European Space Agency (ESA) but now operated by EUMETSAT, has been in geostationary orbit since December 1977. METEOSAT is a spin-stabilized spacecraft, stationed on the Greenwich meridian. At the beginning of ISCCP data collection, imaging data were obtained from METEOSAT-2. The subsequent operations history is given in Table 3.1.

METEOSAT carries a multispectral imaging radiometer which observes the Earth in three spectral regions, one in the visible (≈ 0.75 μm) and two in the infrared (6.7 and 11.3 μm) (Morgan 1978). Higher resolution (2.5 km) visible images can be obtained by turning off the water vapor (6.7 μm) channel. Full Earth images are obtained every half-hour, requiring twenty five minutes to step the telescope from south to north and five minutes for retrace and stabilization. The spacecraft spinning motion scans the telescope across the Earth from east to west. Tables 3.2 and 3.3 show more detail.

Table 3.1. Satellite Operations Histories after 1 July 1983.

Satellite	Period of (Near) Continuous Operations
NOAA-7	July 1983 - February 1985
NOAA-8	October 1983 - June 1984
NOAA-9	January 1985 - November 1988
NOAA-10	December 1986 - October 1991
NOAA-11	October 1988 - September 1994
NOAA-12	September 1991 - present
NOAA-14	January 1995 - present
METEOSAT-2	July 1983 - August 1988
METEOSAT-3	August 1988 - June 1989, January 1990 - April 1990
METEOSAT-3	May 1992 - April 1995 (AS GOES EAST)
METEOSAT-4	June 1989 - January 1990, April 1990 - February 1994
METEOSAT-5	February 1994 - present
GOES-5	July 1983 - July 1984
GOES-6	July 1983 - January 1989
GOES-7	April 1987 - January 1996
GOES-8	March 1995 - present
GOES-9	January 1996 - present
GMS-1	January 1984 - June 1984
GMS-2	July 1983 - January 1984, July 1984 - September 1984
GMS-3	September 1984 - December 1989
GMS-4	December 1989 - June 1995
GMS-5	June 1995 - present
INSAT-1B	April 1988 - March 1989

3.1.3. GOES

The USA Geostationary Operational Environmental Satellite (GOES) system consists of two spacecraft in geostationary orbit, called GOES-EAST and GOES-WEST, operated by NOAA. The initial series of these satellites, starting with the NASA prototypes SMS-1 and 2 and continuing with GOES-1, 2, 3, were improved by the addition of a temperature sounding capability first flown on GOES-4. GOES-4 data were collected during the ISCCP Data Management Systems Test, but GOES-5 (EAST) and GOES-6 (WEST) were supplying imaging data at the start of ISCCP data collection. The subsequent operations history is given in Table 3.1.

The spacecraft are spin-stabilized and located over 75°W longitude (GOES-EAST) and 135°W longitude (GOES-WEST). The imaging data come from the visible (≈ 0.68 μm) and infrared window (≈ 11.6 μm) channels of the Visible Infrared Spin-Scan Radiometer (VISSR; the combination of VISSR and the Atmospheric Sounder is known as VAS). The image is obtained by the combination of the north-to-south stepping of the telescope and the west-to-east spinning motion. Full Earth images are produced every half-hour with the visible channel resolution of 0.9 km produced by eight identical detectors which scan across the Earth in parallel. The single IR detector produces an image resolution of 6.9 km. Tables 3.2 and 3.3 show more detail.

GOES-8 (EAST) and GOES-9 (WEST) are the first in a new series of GOES satellites (Menzel and Purdom 1994). GOES-8 began data collection in March 1995 and GOES-9 began in January 1996. These spacecraft are three-axis stabilized, so that both the Imager and Sounder systems scan Earth by stepping tilting mirrors in a raster pattern from north-to-south and alternating east-to-west, west-to-east. Images are obtained in five spectral bands, one visible band (0.65 μm), one near-IR band (3.9 μm) and three thermal infrared bands (6.75, 10.7 and 12.0 μm). Full Earth images can be produced in about 27 minutes, but are routinely collected only at synoptic times at three hour intervals. Near-nadir resolution in the visible band is 1.0 km, obtained by eight identical detectors that are scanned together by the mirror. A single detector produces a resolution of 8 km for the 6.75 μm channel and a pair of detectors produce a resolution of 4 km for the 3.9, 10.7 and 12.0 μm channels. Tables 3.2 and 3.3 show more detail.

3.1.4. GMS

The Geostationary Meteorological Satellite (GMS) is operated by the Japan Meteorological Agency (JMA). GMS-1 was launched in July 1977 and remained operational until replaced by GMS-2 in December 1981. GMS-2 supplied imaging data for ISCCP beginning 1 July 1983. The subsequent operations history is given in Table 3.1.

The GMS is a spin-stabilized spacecraft maintained at 140°E longitude. Imaging data are from the Visible Infrared Spin-Scan Radiometer (VISSR), with high resolution (1.25 km) visible (≈ 0.65 μm) images obtained by four identical detectors scanning in parallel. Infrared (≈ 11.5 μm) images are produced by a single detector with a resolution of about 5 km at nadir (MSC 1984). The spin-scan motion is from west-to-east and from north-to-south. More details are given in Tables 3.2 and 3.3.

Although the GMS-5 satellite is the same as the previous satellites in this series, the imager instrument on GMS-5 differs from the previous ones in having two additional IR channels. The visible (≈ 0.75 μm) images are obtained by four identical detectors scanning in parallel producing a nadir resolution of 1.25 km. Infrared (≈ 6.9, 10.8 and 11.5 μm) images are produced by single detectors with a nadir resolution of 5 km. The format of images has been changed to accommodate the extra channel within the original data format (see Tables 3.2 and 3.3).

3.1.5. INSAT

The Indian National Satellite System (INSAT) was developed by the Indian Space Research Organization to provide, among other services, meteorological imagery to the Indian Meteorological Department. INSAT is a three-axis stabilized satellite operated since September 1983 in geostationary orbit with a sub-satellite longitude of 74.5° E. INSAT-1B operated well into 1989 when it was replaced by INSAT-1C (INSAT-2 was launched in the summer of 1992). Only limited data have been obtained from INSAT-1B: twice-daily imagery for January 1986 - March 1988 and eight-times-daily imagery for April 1988 - March 1989.

The INSAT radiometer, called the Very High Resolution Radiometer (VHRR), has four VIS (0.55-0.75 μm) detectors with a nadir resolution of 2.75 km and one IR (10.5-12.5 μm) detector with a nadir resolution of 11.0 km. There is also a back-up set of detectors (see Tables 3.2 and 3.3).

Table 3.2. Meteorological satellite characteristics

	NOAA	METEOSAT	GOES	GMS
ORBIT CHARACTERISTICS				
Longitude (geosync)	NA	0°E	75°W,135°W	140°E
Crossing time (Polar)	1430 (ascending)	NA	NA	NA
SCAN CHARACTERISTICS				
Scan system	Spacecraft orbital motion plus scan mirror	Spacecraft spin motion plus scan mirror	Spacecraft spin motion plus scan mirror	Spacecraft spin motion plus scan mirror
Scan direction	Along orbit (approx. S→N in local day and N→S in local night)	Stepping S→N Scan E→W	Stepping N→S Scan W→E	Stepping N→S Scan W→E
No. of steps	NA	2500	1821	2500
Spin rate (rpm)	3-axis stabilized (360 rpm scan)	100	100	100
Image scan area				
Image viewing angle (degree)	$\pm 55.4^{\circ}$ (nominal)	$18^{\circ} \times 18^{\circ}$	$20^{\circ} \times 20^{\circ}$	$18^{\circ} \times 18^{\circ}$
Sector	-----	-----	Full E-W coverage With programmable N-S coverage	-----

Table 3.2. (Continued)

	NOAA	METEOSAT	GOES	GMS
DETECTOR CHARACTERISTICS				
System optics	20.3 cm dia. Focal Cassegrainian telescope	40.0 cm dia. Ritchey-Chretien telescope	40.6 cm dia. Ritchey-Chretien telescope	40.6 cm dia. Ritchey-Chretien telescope
Detector (IFOV μrad)				
IR	1 InSb(1300) 1 HgCdTe(1300)	2 HgCdTe(140)	2 HgCdTe(192 × 192) 2 HgCdTe(385 × 384) 2 HgCdTe(425 × 425)	2 HgCdTe(140)
VIS	2 Si (1300)	2 Si (65)	8 PMT [20(E-W) × 25 (N-S)]	8 PMT (35)
Satellite resolution (km), (μrad)				
IR	1.1, 1300	5,140	6.9, 192	5, 140
VIS	1.1, 1300	2.5, 65	0.9, 20 × 25	1.25, 35
Wavelength (μm)				
IR	10.3-11.3, 11.5-12.5	10.5-12.5	10.5-12.5	10.5-12.5
VIS	0.58-0.68, 0.725-1.0	0.4-1.1	0.55-0.75	0.55-0.75
Other Channels				
WV	3.55-3.93	5.7-7.1	-----	-----
NEΔT				
IR	0.12K at 300K	<0.4K at 300K	0.11K at 300K	<0.5K at 300K
WV	-----	<1K at 260K	-----	<1.5K at 220K

Table 3.2. (Continued)

	NOAA	METEOSAT	GOES	GMS
S/N				
VIS	>3:1 at 0.5% albedo	>4:1 at 0.5% albedo	2.5:1 at 0.5% albedo	>1.4:1 at 0.5% albedo
MTF (optics plus detector)				
IR(WV)	>0.3 for f<385	0.5 for f<2800	>0.12 for f<2500	-----
VIS	>0.3 for f<385	>0.5 for f<5600	1 for f<8000	-----
Digital bits/frequency response (bandwith)				
IR	10/40 kHz	8/30 kHz	8/26 kHz	8/260 kHz
VIS	10/40 kHz	6/60 kHz	6/225 kHz	6/260 kHz
IMAGING CHARACTERISTICS				
No. of lines				
IR	12240 (GAC) (all channels)	2500 (+ WV)	1821	2500
VIS	12240 (GAC) (all channels)	5000	14568	10000
Samples/line				
IR	409 (GAC)	2500	3822	6688
VIS	409 (GAC)	5000	15288	13376
Line duration (msec)	48	30	33	-----
Line recurrence (msec)	167	600	600	600
Image-taking duration (min)	102-minute orbit	25	18.2	25
Frame time (min)	NA	25	30	25

Table 3.2. (Continued)

	GOES-NEXT	GMS-5	INSAT-1B
ORBIT CHARACTERISTICS			
Longitude (geosync)	75° W, 135° W	140° E	74.5° E
Crossing time (Polar)	NA	NA	NA
SCAN CHARACTERISTICS			
Scan system	Raster scan motion by two axis mirror	Spacecraft spin motion plus scan mirror	Raster scan motion
Scan direction	Stepping N→S Alternating E→W, W→E	Stepping N→S Scan W→E	Slow N→S, fast alternating E→W, W→E
No. of steps	1973	2500	1137
Spin rate (rpm)	NA	100	NA
Image scan area			
Image viewing angle (degree)	19.2° × 19.2°	18° × 18°	19.97° × 19.97°
Sector	U.S. and South Pacific, Northern & Southern hemisphere	-----	5° frames

Table 3.2. (Continued)

	GOES-NEXT	GMS-5	INSAT-1B
DETECTOR CHARACTERISTICS			
System optics	30.1 cm Cassegrain telescope	40.6 cm dia. Ritchey-Chretien telescope	??
Detector (IFOV μrad)			
IR	6 HgCdTe (112) at 3.9, 10.7, 12.0 μm 2 HgCdTe (224) at 6.75 μm	6 HgCdTe (140) at 6.9, 10.8, 11.5 μm	1 HgCdTe (307)
VIS	8 Si (28)	8 PMT (35)	4 Si (76)
Satellite resolution (km), (μrad)			
IR	4, 112 at 3.9, 10.7, 12.0 μm 8, 224 at 6.75 μm	5, 140	11.0, 307
VIS	1.0, 28	1.25, 35	2.75, 76
Wavelength (μm)			
IR	10.2-11.2, 11.5-12.5	10.3-11.4, 11.0-12.1	10.5-12.5
VIS	0.52-0.72	0.50-0.99	0.55-0.75
Other Channels			
WV	3.8-4.0, 6.5-7.0	6.7-7.2	-----
NEΔT			
IR	0.2K at 300K 0.4K at 230K	< 0.5K at 300K < 1.5K at 220K	0.2K at 300K
WV	-----	0.3K at 230K	-----

Table 3.2. (Continued)

	GOES-NEXT	GMS-5	INSAT-1B
S/N			
VIS	3σ = 0.8%	>1.4:1 at 0.5% albedo	1.7:1 at 0.5% albedo
MTF (optics plus detector)			
IR (WV)	-----	-----	-----
VIS	-----	-----	-----
Digital bits/frequency response (bandwidth)			
IR	10/130 kHz	8/260 kHz	8/26 kHz
VIS	10/1700 kHz	6/260 kHz	6/160 kHz
IMAGING CHARACTERISTICS			
No. of lines			
IR	2708	2500	1024
VIS	10832	10000	4096
Samples/line			
IR	5208	3344	1024
VIS	20832	13376	4096
Line duration (msec)	1159	-----	1200
Line recurrence (msec)	1159	600	1215
Image-taking duration (min)	27	25	30
Frame time (min)	22	25	23

3.2. STAGE A DATA DESCRIPTION

Table 3.3 summarizes the characteristics of the imaging data produced by the operational weather satellites. Total data volume, if stored on 6250 bpi data tapes (containing about 125 Mbyte of data, assuming average format efficiency), is over 60,000 tapes per year. Visible channel images are generally of much higher resolution than IR images, the former ranging between 1 - 4 km and the latter between 4 - 11 km. The NOAA polar orbiters can provide data with 1 km resolution for limited areas, but global data are only available at 4 km resolution. The polar orbiter collects data continuously, completing about 14 orbits per day; Stage A data are all orbits at 4 km resolution. The geostationary satellites can provide full Earth images every half-hour, but are not usually collected this frequently. Stage A data from the geostationary satellites are defined as full resolution images collected eight times per day starting near 0000 GMT.

3.3. DATA VOLUME REDUCTION PROCEDURE

The SPCs for each satellite collect Stage A data and reduce the volume as illustrated in Table 3.3. Stage B1 data are produced by averaging visible channel data (if necessary) to match the IR channel resolution. Some spatial sampling is then performed to remove overlapping image pixels and to produce a common spacing of about 10 km for all satellite data. The sampling scheme for each satellite is indicated by the IR select factor for B1 shown in Table 3.3. Note that GOES-EAST and GOES-WEST data were processed differently, until recently, producing slightly different resolutions along image scan lines. The Global Area Coverage (GAC) data from the polar orbiter, which have 4 km resolution, are retained as the Stage B1 data. Table 3.3 also shows the volume reduction scheme (IR select factor for B2) used to produce Stage B2 by a further spatial sampling. The final reduced radiance data product, produced by the GPC, is Stage B3 which has the same characteristics as Stage B2 shown in Table 3.3. Stage B3 data are made available in a standard format with radiances normalized to the polar orbiter radiometer response which is calibrated. The data volumes in Table 3.3 represent the actual volume of Stage B3 radiance data with no overhead. Complete B3 data would occupy 216 (6250 bpi) tapes per year for two polar orbiters and five geostationary satellites. Typical Stage B3 data volume has been equivalent to about 170-190 tapes per year.

Table 3.3. Characteristics of operational imaging radiometers and estimated ISCCP data volumes

Satellite	NOAA	METEOSAT	GOES-EAST	GOES-WEST	GMS
VIS resolution (km at nadir)	4.0	2.5	0.9	0.9	1.25
IR resolution (km at nadir)	4.0	5.0	6.9	6.9	5.0
other channel resolution [1]	4.0	5.0	-	-	-
IR resolution (µrad)	1300[2]	140	192	192	140
IR E-W pixel step (µrad)	-	125	84	84	48
IR N-S line step (µrad)	-	125	192	192	140
VIS pixels in line	409[3]	5000	15288	15288	13376
VIS lines in image	12240[3]	2500	14568	14568	10000
IR pixels in line	409[3]	2500	3822	3822	6688
IR lines in image	12240[3]	2500	1821	1821	2500
IR select factor for B1					
along a line	1	2	2	3	6
line to line	1	2	1	1	2
Full 10km resolution (IR/VIS)					
pixels in line	409[3]	1250	1911	1274	1114
lines in image	12240[3]	1250	1821	1821	1250
Approximate B1 archive					
pixels in line	409[3]	1250	1911	1230	1100
lines in image	12240[3]	1250	1821	1700	1100
IR Select factor for B2					
along a line	6	3	4	3	3
line to line	8	3	4	4	3
B2 archive (trimmed)					
pixels in line	65	416	477	413	367
lines in image	1530	416	455	455	367
B2 E-W spacing at nadir (km)	24	27	25	28	31
Data Volume (10^9 bits/yr)					
A	1640[3]	2200	25000	25000	4600
B1[4]	1640[5]	92[6]	126	82	48
B2[7]	32	11.0	9.5	7.8	6.0

(1) METEOSAT and GMS-5 have three spectral channels; GOES-NEXT and NOAA have five.
(2) Intrinsic FOV; on-board averaging reduces resolution from 1.1 km to nominal 4.0 km.
(3) NOAA numbers are for one orbit swath, whereas others are for whole Earth image.
(4) Assumes 5% overhead is balanced by 5% data loss. All pixels stored in 8 bits, except for NOAA. Visible data volume is reduced by 37% by deleting 3 night images for geostationary satellites.
(5) Radiances stored as 10 bit numbers.
(6) Based on actual format but with overhead offset by data loss.
(7) Assumes 20% overhead.

Table 3.3. Continued.

Satellite	GOES-NEXT	GMS-5	INSAT-1B
VIS resolution (km at nadir)	1.0	1.25	2.75
IR resolution (km at nadir)	4.0	5.0	11.0
other channel resolution (1)	8.0, 4.0	5.0	– – –
IR resolution (μrad)	112	140	307
IR E-W pixel step (μrad)	87	96	307
IR N-S line step (μrad)	87	140	307
VIS pixels in line	20832	13376	8000
VIS lines in image	10832	10000	4548
IR pixels in line	5208	3344	2000
IR lines in image	2708	2500	1137
IR select factor for B1			
along a line	4	3	1
line to line	2	2	1
Full 10km resolution (IR/VIS)			
pixels in line		1114	1024
lines in image		1250	1024
Approximate B1 archive			
pixels in line	1172	1100	1024
lines in image	1332	1100	1024
IR Select factor for B2			
along a line	3	3	2
line to line	4	3	2
B2 archive (trimmed)			
pixels in line	392	367	500
lines in image	333	367	510
B2 E-W spacing at nadir (km)	24	31	22
Data Volume (10^9 bits/yr)			
A	5765(5)	5270	1115
B1(4)	170	104	40.9
B2(7)	17	13.9	9.7

(1) METEOSAT and GMS-5 have three spectral channels; GOES-NEXT and NOAA have five.
(2) Intrinsic FOV; on-board averaging reduces resolution from 1.1 km to nominal 4.0 km.
(3) NOAA numbers are for one orbit swath, whereas others are for whole Earth image.
(4) Assumes 5% overhead is balanced by 5% data loss. All pixels stored in 8 bits, except for NOAA. Visible data volume is reduced by 37% by deleting 3 night images for geostationary satellites.
(5) Radiances stored as 10 bit numbers.
(6) Based on actual format but with overhead offset by data loss.
(7) Assumes 20% overhead.

3.4. GLOBAL PROCESSING CENTER OPERATIONS

Fig. 3.1 illustrates the data processing flow at the GPC and indicates the major functions in the data processing and analysis. The satellite radiance data and correlative data are received in monthly installments from the SPCs and NOAA/NESDIS, respectively. Readability checks and copies of all data are completed and quality notifications sent to all centers. Normalization coefficients are received from the SCC. B3 datasets are created by formatting the radiance data, navigating the image pixels and appending the normalization/ calibration information. B3 data appear to the user to be uniform in format and information content, but the original image format and data values are preserved. Stage B3 data are then sent to the ISCCP Central Archive.

All ISCCP radiance data pass through four levels of quality inspection: operational quality control by the satellite operators, quality control by the SPCs when processing Stage A data to stage B1/B2, quality control by the GPC when processing Stage B2 data to Stage B3, and final quality inspection by the GPC, which includes checks on navigation and calibration. After the first three levels of quality checks have been passed, very few problems remain; however, a final inspection is needed to detect smaller changes which affect the accuracy of the cloud analysis. The final inspection has three stages: collection of image statistics over a whole month, identification of anomalous images, and visual inspection of anomalous images. The basic principle of this procedure is that data errors cause the average properties of an image to deviate more than "normal" from the monthly mean value. The monthly average and standard deviation of each of the following quantities is calculated for each 3-hour time period during a day:

a. image mean radiance counts and physical radiances (to check calibration)

b. radiance values representing the 10th, 25th, 50th, 75th and 90th percentiles in the image radiance distributions

c. the entropy of the radiance distributions (a measure of variability)

d. (approximate) sub-satellite and sub-solar point latitudes and longitudes

e. total number of image pixels and number of pixels classified as day, night, land, water, coast and off-planet

f. distribution of scan line autocorrelations of radiances and viewing angles

g. distribution of scan line cross-correlations of VIS-IR radiances

h. distribution of scan-line-averaged radiances

i. distribution of pixel-column-averaged radiances

Images with too many high ($>3\sigma$) deviations are labeled as anomalous. All anomalous images are then visually inspected to determine the nature and extent of the problem. A few percent of the images that pass the automated checking are selected at random for visual inspection as well.

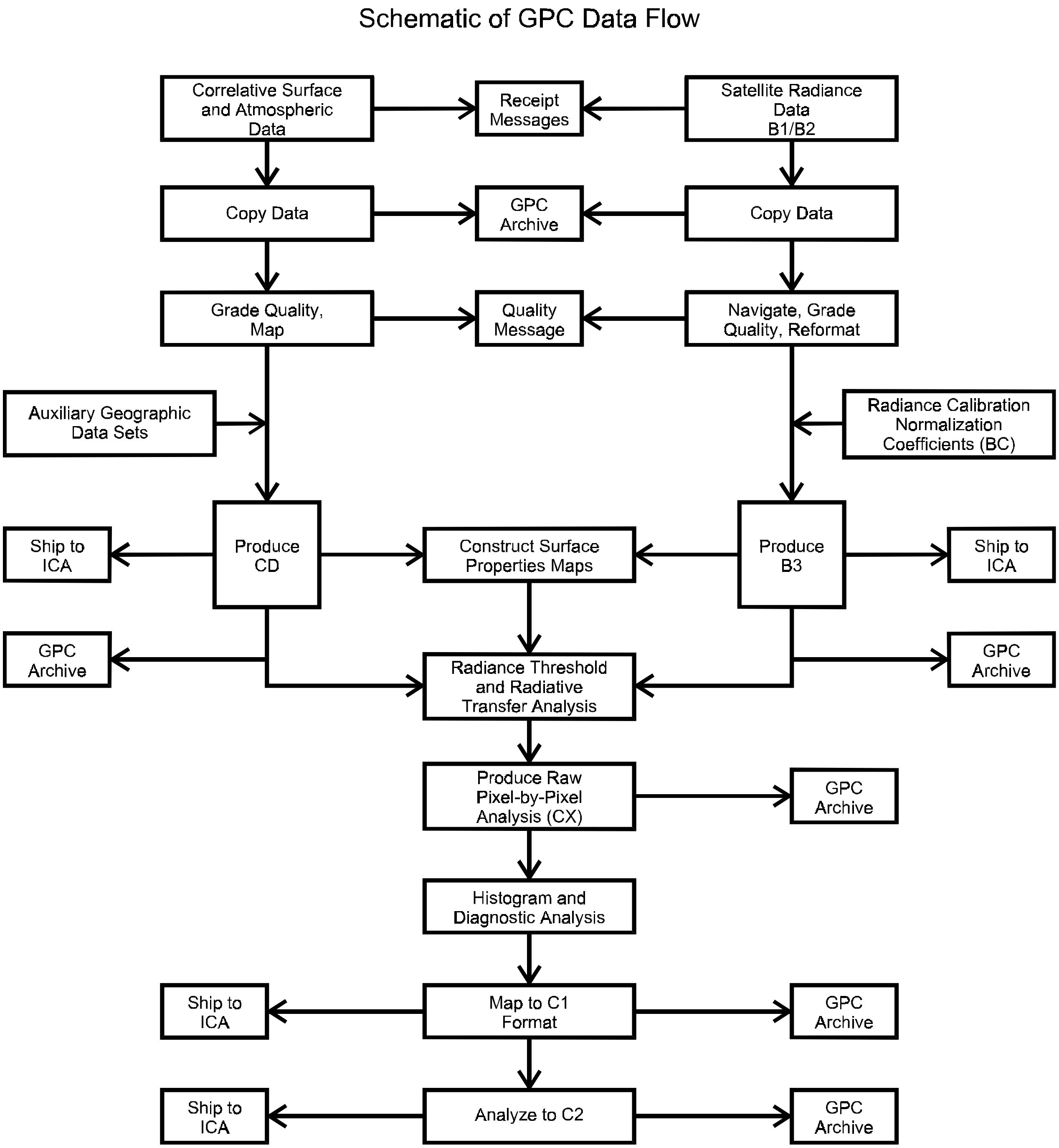

Figure 3.1. Schematic of the GPC data processing flow.